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APPARATUS AND METHOD TO MEASURE FILM MOTION IN A FILM GATE

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APPARATUS AND METHOD TO MEASURE FILM MOTION IN A FILM GATE

FIELD OF THE INVENTION

The present invention relates to measurement methods, and more particularly to apparatus for measuring the motion of a film in a film gate such as the projection gate of a motion picture projector, scanning gate in a film scanner, or recording gate in a film recorder.

BACKGROUND OF THE INVENTION

During the projection of motion picture film the projected image on the screen can go in and out of focus resulting in momentarily blurred images reducing the picture quality on the projection screen causing discomfort to the viewer. There is a desire to maintain the sharpness of the projected image by keeping the film plane in focus and to eliminate the in and out of focus movement of the film which is objectionable to the viewer. It is known in the art that both thermal and mechanical induced motions will cause the film to go into and out of focus resulting in these undesirable effects.

During motion picture projection, successive film frames are transported intermittently. In a standard 24 frame per second 2 bladed shutter motion picture projection system, each film frame sees an approximately 40 ms cycle divided into four approximately 10 ms events. During the first event a new film frame is advanced and positioned into the film gate while the shutter is closed. During the second event the shutter opens rapidly and the stationary film frame is exposed to high intensity primary light source illumination. During the third event the shutter is closed rapidly and the film frame remains stationary. During the fourth event the shutter is again opened rapidly exposing the stationary film frame to high intensity primary light source illumination for a second time. After the fourth event the shutter is closed and the film is advanced to the next frame and the cycle is repeated.

The mechanical induced motion occurs during the transport event of the projection cycle. When the film is intermittently pulled through the gate, the film moves in and out of the plane defining the rest position. This in and out

of the plane motion is called mechanical ringing and typically takes about 30 ms to settle. The thermal induced motion occurs during the second through fourth events. When the shutter is opened the film absorbs radiant energy from the high intensity primary light source and expands, which causes thermally induced motion. The film is heated during the first and second exposures (second and fourth events) and cools when the shutter is closed during the third event.

The current trend in the motion picture industry is to project onto larger screens, which require higher levels of illumination on the film in the projector gate. These higher levels of illumination amplify the undesirable thermal effects. These effects differ from one projector to the next, each projector having its own peculiar characteristics. This problem of thermal and/or mechanical deflection of film in a gate is also experienced in film scanners, film writers, photographic printers, and slide projectors.

Film scanners and film recorders are similar to film projectors in that they have film transport subsystems and high intensity illumination sources. Film projectors, scanners, and recorders require the film to be accurately positioned and include apparatus to maintain positional accuracy during operation. Radiant energy absorbed by the film from the illumination source causes the film to move or buckle. The film transport subsystems, at the component level, introduce mechanical vibrations into the film causing it to move or ring. The film motion characteristic profiles for thermal and mechanical induced motions are critical in order to maintain proper focus calibration with the rest of the optical system. The typical depth of focus requirements for precision film scanners, recorders, and projectors is less than four thousandths of an inch over the field of view. In order to properly design, assemble, align, calibrate, operate, and maintain precision film apparatus, real-time monitoring of the film dynamics is critical to meeting the performance criteria.

Film scanners transport film across a film gate. Typically, they illuminate from one side through the film onto a detector which is located on the other side of the film. The optical subsystem defines the planarity of the film at the film gate. Any motion, thermal and/or mechanical, which causes the film to displace beyond the depth of focus specification will result in a degraded, out of

focus image. Real-time accurate film position data provides the opportunity to maintain in-spec performance and ensure optimal image scanning.

Film recorders typically transport film across a writing head in which a precision beam of light writes or exposes a latent image on the light sensitive film. The planarity of the film's surface is required to be controlled within very tight tolerances in order to properly focus the beam on the surface. The resulting image quality is directly dependent on controlling film motion within the depth of focus of the optical system. Real-time accurate film position data provides the opportunity to maintain in-spec performance and ensure optimal image recording.

Thus, there is a need for real time instrumentation to characterize and enable understanding of the thermal and mechanical induced motions of the film as it is transported, illuminated and/or projected in the gate of a motion picture projector, film scanner or film recorder. The resulting knowledge will enable the design of improved motion picture projection systems, scanners and film recorders. For example, use of the instrumentation will enable better construction, alignment and calibration of motion picture projectors, film scanners and film recorders. In addition the same type of instrument can be utilized in the field for maintenance, repair and calibration of motion picture film projectors, film scanners and film recorder. The instrumentation can also be integrated into the motion picture film projector, film scanner or film recorder to provide active monitoring and real time feedback to servo control systems to maintain in-spec focus.

US Patent 3,471,225 issued October 7, 1969 to Hutchison describes an automatic focusing motion picture projector which attempted to measure the buckle of the film at a frame adjacent to the projector film gate. The apparatus includes a light source arranged to project a beam of light at an obtuse angle onto the surface of the film and a split detector arranged to receive the reflected beam from the surface of the film. This arrangement does not actually measure the film deflection in the gate of the projector and does not provide a record of the deflected film as a function of time. The measurement looked for a desired

amplitude and controlled a servo mechanism to keep the film at a desired distance. There was no means included to determine the magnitude of the film buckle.

US Patent 3,672,757 issued June 27, 1972 to Szymber et al. discloses a slide projector means for maintaining focus in response to film deflection similar in principle to that of US Patent 3,471,225. US Patent 4,800,286 issued January 24, 1989 to Brears discloses a measurement device for computing distance variations in a corrugated structure with a fiber optic lens probe and a detector sensing reflected light variations from peaks and valleys of the corrugated structure. US Patent 5,483,347 issued January 9, 1996 to Hollmann discloses an apparatus for measuring distance wherein a light source from one fiber optic bundle is focused on a surface and reflected light therefrom is focused through another fiber optic bundle to a detector for calculation of the distance. In this apparatus the fiber optic probe is moved relative to the stationary object surface for calculating distance. US Patent 5,581,351 issued December 3, 1996 to Marcus et al. discloses a method and apparatus for measuring thermal expansion of a rotating roller utilizing a pair of reflective fiber optic probes. US Patent 5,392,123 issued February 21, 1995 to Marcus et al. describes an optical monitor for measuring a gap between a pair of rollers using a plurality of reflective pair fiber optic probes.

None of the above prior art will measure film deflection and dynamics in real time in the gate during the intense illumination from the primary light source present at the gate of a motion picture projector. Therefore, there is a need for an improved apparatus for measuring the out of plane motion of motion picture film traveling through the gate of a motion picture projector during illumination by high intensity optical sources. Furthermore, such an apparatus needs to be self-calibrating, robust, simple to install, be capable of making measurements in real time, and with high measurement reproducibility on the order of 1-micron measurement repeatability. Thus, there is a need for improved instrumentation to characterize thermal and mechanical induced deflections of motion picture film as it is transported, illuminated and projected in the gate of a motion picture projector.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing apparatus for measuring deflection of a film in a film gate having an aperture illuminated by a primary light source having an output spectrum, that includes:

a) a reflective photonic probe mounted in the film gate, the reflective photonic probe having at least one optical fiber;

b) a measurement light source coupled to a reflective photonic probe and emitting a wavelength of light outside of the primary light source's spectrum;

c) a photodetector coupled to the reflective photonic probe;

d) a narrow pass optical filter located between the photodetector and the reflective photonic probe, the narrow pass filter passing the light from the measurement light source and blocking the light from the primary light source; and

e) signal processing electronics connected to the photodetector for producing a signal representing the motion of the film perpendicular to the plane of the film.

ADVANTAGES

The present invention enables the design of improved motion picture projection systems, film scanners and film recorders. Use of the instrumentation will enable better construction, alignment and calibration of motion picture projectors, film scanners and film recorders. In addition the same type of instrument can be utilized in the field for maintenance, repair and calibration of motion picture film projectors, film scanners and film recorders. The instrumentation can also be integrated into the motion picture film projector, film scanner or film recorder to provide active monitoring and real time feedback to servo control systems to maintain in-spec focus.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a typical (prior art) motion picture projector highlighting the projector film gate, tensioning control, transport drives, rollers and film path;

Fig. 2 shows a first schematic of the apparatus according to the present invention used to measure motion picture film motion at the image plane during projection;

Fig. 3 shows a preferred embodiment for the apparatus shown schematically in Fig. 2;

Fig. 4 shows an alternate embodiment for the apparatus shown in Fig. 2;

Fig. 5 shows further detail of the fiber optic reflective probe mounted into the projector gate;

Fig. 6 shows typical calibration curves for the pair of optical fibers shown in Fig. 3 along with the ratio of the two signals for an OD 3 film;

Fig. 7 shows typical ratio calibration curves for a variety of motion picture films;

Fig. 8 shows typical data measured with the motion picture gate moving without the primary light source on;

Fig. 9 shows typical data with motion picture projector primary light source and shutter active; and

Fig. 10 shows a high speed video camera looking at the film in the projector film gate at an oblique angle together with the optical probe.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 depicts a typical motion picture projector head **10** with a motion picture film **20** threaded through the projector head. A film supply **14** holds the film **20** which is threaded around a supply drive **32**, forming an upper loop **13** into a film gate **25**, around an intermittent drive **17**, down to form a lower loop **18**, around the take-up drive **34** where the film is wound onto a film take-up **36**. The tension on the film inside the gate is controlled by a film tension control **16**. This eliminates slack in the film and provides a flat film surface at the gate

aperture, which minimizes lateral and longitudinal film motion and provides for a sharper projected image. The projector primary light source **12** is used to illuminate the motion picture film **20** with a particular primary light source output spectrum usually optimized for a high output over the entire invisible wavelength range. The projector primary light source **12** is held in a projector primary light source housing (not shown) and has a reflector (not shown) mounted in the projector primary light source housing behind the primary light source. The reflector and primary light source are positioned to provide a desired cone of light at a film gate aperture **26.** The film is illuminated through the projector gate film aperture **26**, which determines the illuminated region of the film. During transport the projector gate film aperture **26** is coincident with the motion picture film image frame, and the projected image passes through lens **30** and is displayed on a projection screen (not shown). A shutter **15** is typically a two bladed device that breaks the projected light beam into two equal time exposures and is timed to the intermittent cycle. The quality of the projected image is dependent on the projector's ability to properly contain the film in the gate during the two time exposures. The intensity of the light beam introduces thermally induced buckling of the film in the gate and causes the film to move in and out of focus.

The motion picture projector outputs a high quality analog image that can be defined by six image parameters: brightness, steadiness, flicker, noise, sharpness, and ghosting. The transport subsystem of the projector, including film tension, contributes to the unsteadiness, noise, and sharpness of the projected image. The magnitude of the primary light source's flux density determines the amount of thermal buckling which results in reduced sharpness, increased unsteadiness, and the amount of perceived flicker.

In order to have complete control over the film during all phases of operation, a complete characterization is needed which isolates mechanical and thermal characteristics. These profiles can be used to provide proper alignments, subsystem timing, tension adjustments, and primary light source focus during initial calibration and for passive and/or active compensation during operation.

Fig. 2 shows a general schematic of the apparatus according to the present invention to measure motion picture film motion at the image plane during

projection. A small diameter fiber-optic coupled reflective photonic probe **60** is mounted perpendicular to the film plane of a film **20** in a motion picture projector head **10** in front of the primary light source housing at the film gate. The reflective photonic probe **60** includes a pair of optical fibers **71** and **74**, the ends of which are mounted parallel and at a fixed spacing relative to each other in a tubular probe casing **59**. A measurement light source **70**, preferably a narrow band light source such as a laser, is coupled to an input optical fiber **74** which functions as the input fiber to reflective photonic probe **60**.

The ends of fibers **74** and **71** residing in the reflective photonic probe **60** are cleaved and polished flat normal to the fiber axis. It is noted that optical fibers **74** and **71** can either be single optical fibers or fiber optic bundles. Light emanating from probe input optical input fiber **74** comes out within a cone of light determined by the numerical aperture (NA) of the fiber. When a reflective surface is placed below the tip of probe **60**, only light reflected off of the reflective surface which falls within the detection fiber's numerical aperture (NA) is collected by the detection optical fiber **71**.

When no reflective surface is present, there is no light detected. The observed signal amplitude due to the presence of a reflective surface is dependent on its distance from the probe tip, the reflectivity of the surface, the fiber numerical aperture, the fiber core diameter, the center to center fiber spacing, the light source intensity, and the angle the reflective surface makes with respect to the probe surface. Further details on the design of the reflective photonic probe **60** are found in SPIE Proceedings Vol. 2836, M. A. Marcus, "Robust Fiber Optic Sensors For Process Monitoring And Control Applications", pp. 118-129, 1996. Alternatively, as described in the Marcus paper, the reflective photonic probe **60** can include a single fiber that is used both for input and output.

When the projector primary light source **12** is on and the shutter is open, light incident from the projector primary light source will also be coupled into detection optical fiber **71**. A narrow band pass filter **90** placed at the distal end of optical detection optical fiber **71** transmits light from measurement light source **70** while eliminating the majority of the light from the projector primary light source. In order for filter **90** to remove the majority of the light from the

projector primary light source, the measurement light source **70** must emit at a wavelength which has minimal overlap with light coming from the projector primary light source.

The light passing through filter **90** is input into photodetector **81**. Photodetector **81** converts the portion of the light from measurement light source **70** reflecting off the motion picture film **20** and passing through filter **90** into an analog voltage signal proportional to the light intensity. The analog voltage signal is sent to an analog to digital converter in computer and data acquisition system **100** where it is analyzed as a function of time.

The reflective photonic probe **60** is set up at an appropriate distance in front of the film so that the detected reflected optical signal is a monotonically increasing or decreasing function of distance from the film surface. When the projector is on, the film is transported through the projector's film gate in an intermittent frame-by-frame manner, and the change in location of the film plane is detected continuously as a function of time.

Fig. 3 shows a schematic of a preferred embodiment of the apparatus used to assess the motion picture film motion at the imager plane of a motion picture projector. The main difference from the embodiment shown in Fig. 2 is that the reflective photonic probe **60'** includes a pair of detection optical fibers **71**, **72** and a pair of photodetectors **81**, **82**. This arrangement is called a reflectivity compensated probe. In addition, a separate optical fiber **73** is included to detect light from the projector primary light source that transmits through the motion picture film **20**.

The light passing through the projector film gate from the projector primary light source transmitting through optical fiber **73** is detected by projector primary light source photodetector **83**. The optical signal detected by projector primary light source photodetector **83** is utilized as an indicator that the projector primary light source housing shutter is open. As before, photodetectors **81**, **82** and **83** convert the received optical signals into analog voltage signals proportional to their respective received light intensities. The analog voltage signals are sent to analog to digital converters in the computer and data acquisition system **100** where they are analyzed as a function of time.

Fig. 4 shows an alternate preferred embodiment in which the optical fiber **73** is split off from one of the reflective photonic probe detection fibers **72** by a one by two coupler **75**. An optional light source notch filter **93** is utilized to remove light from measurement light source **70** so that only light coming from the projector primary light source **12** transmitted through the motion picture film **20** is detected by photodetector **83**. The light source notch filter **93** is designed so that it has minimal transmission at the laser wavelength of measurement light source **70** and almost 100 percent transmission everywhere else.

Fig. 5 shows the mounting geometry for optical reflective photonic probe **60** into the projector film gate **25**. Also shown are projector primary light source **12**, projector shutter **15**, projector gate film aperture **26**, film perforations **21** and the projector gate film clamp **22**. The probe to projector gate mounting arrangement also includes a probe to film gate clamp adapter base **66** directly coupled to the projector gate film clamp **22**. It also includes a micrometer base **64** with a z-axis micrometer **62** installed in it attached to the probe to film gate clamp adapter base **66** for controlling the z-axis distance of the reflective photonic probe **60** tip from the surface of the motion picture film **20**. The probe to film gate clamp adapter base **66** also includes a y-axis micrometer **65** and a x-axis micrometer **67**.

Also shown in the bottom right of Fig. 5 is the coordinate system. The z-axis micrometer is used when performing a distance calibration on the reflective photonic probe **60**. The x-axis and y-axis micrometers **67** and **65** are used to map out a distribution of the film motion over the surface of the projector gate aperture **26** during testing. In addition, the signal from the projector primary light source photodetector **83** can be used to map the projector primary light source's **12** flux density distribution on the motion picture film **20** over the area of the projector gate film aperture **26**. This data can be utilized to adjust the primary light source housing and primary light source reflector position so as to provide uniform illumination throughout the projector gate film aperture **26**. In order to load the motion picture film **20** into the projector film gate **25** the projector gate film clamp **22** tension is released, the film **20** is inserted into guides between the

projector gate film clamp **22** and the projector film gate **25** and the tension to the projector gate film clamp **22** is reapplied.

The apparatus shown in Fig. 5 also includes an optional notch filter **91** whose function is to eliminate any residual light at the laser wavelength of measurement light source **70** emitted by projector primary light source **12** before it is transmitted through the film **20**. The notch filter **91** is designed so that it has minimal transmission at the laser wavelength and almost 100 percent transmission everywhere else. Its function is identical to that of light source notch filter **93** shown in Fig. 4.

The reflective photonic probe **60** shown in Figs. 3 and 4 are reflectivity compensated fiber optic probes. They include a pair of detection fiber bundles **71** and **72** with different effective center-to-center distances from the input fiber bundle **74**. The reflective photonic probe **60** was designed to provide a monotonically increasing ratio signal as a function of distance from the probe surface with a linear range in excess of 1 mm. In an example probe design, the active probe tip facing the projector gate, has a 0.125" outer diameter (OD). There is a 90-degree bend in the probe with about a 0.70" radius to facilitate right angle mounting into the probe clamp **64**. The active probe tip consists of a center fiber bundle **61** with a 46-mil outer diameter surrounded by an outer ring of fibers **63** with a 91-mil diameter. Individual fibers in the fiber bundles are 3.5-mil in diameter with a numerical aperture (NA) of 0.25. The central fiber bundle is randomized and is coupled to two branch tips at the distal end of the fiber probe. One of these branch tips includes input fiber **74** and is coupled to and used for collecting light from measurement light source **70** preferably a laser light source. The second branch tip is coupled to detection fiber **71**, which then passes through narrow bandpass filter **90** and into photodetector **81**. The outer ring of fibers **63** is coupled to detection fiber **72**, which then passes through narrow bandpass filter **90** and into photodetector **82**. The active fiber bundle diameters for input fiber **74** and the distal end of detection fiber **71** are 32 mils and the active fiber bundle diameter at the distal end of detection fiber **72** is 81 mils.

Fig. 6 shows the measured photodetector responses of the inner fiber-optic bundle **61** labeled Probe 2, and outer fiber-optic bundle **63** labeled

Probe 1 along with the calculated scaled ratio of the two signals as a function of distance from the motion picture film. The data in the calibration curve is obtained as follows. Using the z-axis micrometer **62** the tip of reflective photonic probe **60** is first brought into contact with film **20** in the projector gate. The probe voltages for the two channels are recorded and converted to digital signal levels using the data acquisition and computer system **100**. The probe position is then incremented by a known amount (typically in 50 μm steps) and data is recorded using the data acquisition and computer system **100** and stored in a sequential table of probe voltages as a function of distance. This process is continued until the farthest distance data desired is obtained. The scaled ratio as a function of probe tip distance from the film is then calculated by calculating the ratio of the two probe signals at each measured distance and multiplying them by a constant scaling factor. The scaled ratio data is also displayed in Fig. 6.

Fig. 7 shows the measured ratio response for 2 different OD 3 motion picture films and a transparent motion picture film. Note that the ratios as a function of distance for all the films over the range between 0.6 and 2.2 mm are monotonically increasing and are in excellent agreement. This is an example of the results obtained with a reflectivity compensated probe which functions as follows. The individual probe signals S_i can be calculated as follows

$$S_i = C_i I_o F_{li} R g_i f_i(x) \tag{1}$$

where i is the detection fiber branch 1 or 2, I_o is the incoming light intensity from the measurement light source **70**, C_i is the fiber transmission due to coupling loss and fiber transmission percentage, F_{li} is the in-line narrow bandpass filter **90** transmission percentage at the wavelength of the measurement light source **70**, R is the reflectivity of the motion picture film **20**, g_i is the amplifier gain factor of photodetector **81** or **82**, and $f_i(x)$ is the normalized signal response function of the fiber-optic reflective photonic probe detection branch as a function of distance z from the motion picture film **20** surface. The fiber probe signal versus distance function $f_i(x)$ is dependent on the fiber diameter, NA of the fibers and center to center spacing between fibers as well as the number of fibers in the bundle and

fiber bundle geometry. As is demonstrated in Fig. 7 the optical probe ratio signal (S_1/S_2) is independent of film optical density, film reflectivity and is also independent of light source power.

Fig. 8 shows data for a motion picture film being transported intermittently through the gate of a motion picture projector with the primary light source off. In this case, the optical probe mounted in the projector gate is following only the mechanically induced motion of the film. The top trace shows signals of the two probe channels from the reflective photonic probe shown in Fig. 3 as a function of time along with the ratio of the two signals. The bottom trace of Fig. 8 shows the calculated distance as a function of time determined from the ratio signal shown in the top trace of Fig. 8.

The conversion from measured scaled ratio to distance of the reflective photonic probe tip to the film surface is performed as follows. From the calibration data shown in Fig. 6 or 7 we fit the ratio to an equation using regression analysis. For the data shown in Figs. 6 and 7 we assumed a relationship of the form:

$$z = a + bR + c\sqrt{R} + d/\sqrt{R} + e/R + f/R^2 + g/R^3 + h/R^4 \qquad (2)$$

where z is the distance from the probe tip to the film surface, R is the scaled ratio, and a through h are polynomial coefficients calculated during regression analysis. The regression analysis was performed over the distance range from 0.7 mm to 1.8 mm and the best-fit coefficients calculated were found to be:

a	b	c	d	e	f	g	h
3.3803	0.0169	-0.3403	-7.3705	0.6451	31.6312	7.3209	2.0367

In order to convert from measured probe voltages to distance values shown in the bottom trace of Fig. 8, the ratio data is put into equation 2 and the distance values are calculated using the values for coefficients a through h determined by regression analysis from the calibration curve data as summarized in the above table.

The distance data shown in the bottom trace of Fig. 8 shows a transient disturbance at about 40 msec intervals followed by a transient decay of

this disturbance which rings for about 20-30 msec. This transient disturbance is coincident with the intermittent film motion of moving from one frame to the next adjacent frame in the projector gate. The magnitude of the transient disturbance and the time that it takes for the disturbance to level off are mainly determined by film tension, the acceleration profile of the intermittent drive mechanism and sprocket teeth/film interface in the film transport system of the motion picture projector head **10**. This data can be utilized to appropriately tension the film by adjusting film tension control **16** so that the mechanical induced disturbances are minimized.

By measuring the magnitude of mechanical deflection of the film in the gate at a plurality of tensions, an optimum tension that produces a minimal deflection can be determined. A desired phase relationship between a film advance mechanism and a shutter in the projector can also be determined from the measurement of the mechanical deflection. Furthermore, by performing a fast Fourier transform to measure the main frequency components and amplitudes of mechanical deflection of the film in the gate, one can determine which component of the projector contributed to the deflection. The determined component can then be adjusted to control the amplitude of the mechanical motion.

Fig. 9 shows data for the same film when the projector primary light source is turned on and the shutter is functioning normally. The top graph in Fig. 9 shows the calculated distance from the probe to the film surface as a function of time along with the signal from photodetector **83**, which provides a signal indicating when the shutter is open. When the voltage on the shutter signal is high, the shutter is open; and when the voltage is low, then the shutter is closed. The bottom trace in Fig. 9 shows the raw data used to derive the distance data shown in the top trace of Fig. 9. From the shutter signal shown in the top trace of Fig. 9, it is observed that the shutter is alternately opened and closed at approximately 10 msec intervals. At the first shutter open to closed transition shown in the top trace of Fig. 9, occurring at about 10 msec, the film moves intermittently from one frame to the next adjacent frame. This is accompanied by the mechanical motion which occurs between 10 and 20 msec as described above with respect to Fig. 8. At 20 msec the shutter is opened and the film is exposed to

the intense radiation from the projector primary light source which induces a thermal motion occurring between 20 and 30 msec and causes the motion picture film to buckle towards the projector primary light source **12**. Between 30 and 40 msec the shutter is again closed and the thermally induced motion relaxes. Between 40 and 50 msec the shutter is again opened and a second exposure to the intense radiation from the projector primary light source ensues and further thermal buckling occurs and causes the film to move even closer to the projector primary light source. At 50 msec the shutter is again closed and the film is advanced intermittently to the next frame where combined thermal relaxation and intermittent mechanical motion occur. The entire cycle then repeats.

By collecting multiple frames of data with the primary light source off, which provides mechanical ringing data only, and then collecting multiple frames of data with the primary light source alternately on and off which provides mechanical ringing plus thermal buckling data, we can separate the mechanical and thermally induced buckling components of the signal. This is done by subtracting the data obtained with the primary light source off from the data obtained with the primary light source on. By measuring the amplitude of the thermally induced buckling at a plurality of light intensities, a light intensity level which produces the brightest, sharpest image can be determined, thereby taking advantage of any non-linearities in the thermally induced buckling behavior of the film. Furthermore, a mechanical component of the projector, such as film tension, can be adjusted to reduce the amplitude of the thermally induced buckling.

In a preferred embodiment, the y-axis and x-axis micrometer stages would be computer controlled so that the distribution of mechanical ringing and thermal buckling of the motion picture film **20** could be studied over the entire motion picture projector gate aperture **26**. The primary light source spectral distribution can be characterized in terms of flux density profile by adding selective filtration to fiber **73**.

Referring to Fig. 10, a high-speed video camera **92** can be placed at a 10-30° angle from the film plane of the motion picture film **20** to detect the location of the tip of the optical probe and the apparent location of the probe reflection as shown in Fig. 10. When utilizing the high-speed video camera **92** an

external light source **94** is utilized to illuminate the probe tip of reflective photonic probe **60'** and the motion picture film **20** in the projector gate film aperture opening **26**. If the motion picture film **20** is partially reflective then a virtual image of the photonic probe **60'** will occur in the image produced by the high-speed video camera **92**. In general, the reflective photonic probe's tip **60** will be located a distance z from the surface of the motion picture film **20** and the virtual image **60^r** will be located a distance z' from the surface of the motion picture film **20**. The two distances z and z' are equal in magnitude, and the distance from the tip of the reflective photonic probe **60'** to the surface of the motion picture film **20** is calculated to be $(z+z')/2$.

The change in distance between the apparent location of the tip of reflective photonic probe **60'** and the virtual image of the photonic probe **60^r** can be monitored as a function of time using the high-speed video camera **92**. This can only be performed if the motion picture film **20** is at least partially reflective. In order to calibrate the distance motion, a measurement would be made at a distance $z+z'$ and then the z-axis micrometer would be incremented by a known amount i, and the 2 data sets compared. The apparent distance shift in the video image would be 2i for these two data sets. Alternatively, the known diameter of reflective photonic probe **60'** can be used to provide a calibration factor. The reflective photonic probe **60'** data and the high-speed video **92** complement each other.

Dynamic response of the film due to high intensity illumination is successfully measured in real time using these techniques even in the presence of high heat loads from high intensity illumination (7 KW).

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention. For example the apparatus of the present invention can be used in a laser film recorder or a film scanner such as those used to scan motion picture film to create a digital intermediate. In this case the projector primary light source would be replaced with an appropriate laser source for the particular apparatus.

PARTS LIST

10	motion picture projector head
12	projector primary light source
13	upper loop
14	film supply
15	shutter
16	film tension control
17	intermittent drive
18	lower loop
20	motion picture film
21	film perforation
22	projector gate film clamp
25	film gate
26	projector gate film aperture
30	lens
32	supply drive
34	take up drive
36	film take up
59	probe casing
60	reflective photonic probe
60'	reflective photonic probe
60^{r}	virtual image of reflective photonic probe
61	center fiber bundle
62	z-axis micrometer
63	outer fiber bundle
64	micrometer base and probe clamp
65	y-axis micrometer
66	probe to film gate clamp adapter base
67	x-axis micrometer
70	measurement light source
71	detection optical fiber

72	second detection optical fiber
73	optical fiber
74	input optical fiber
75	one by two coupler
81	photodetector
82	second photodetector
83	projector primary light source photodetector
90	filters
91	notch filter
92	high speed video camera
93	light source notch filter
94	external light source
100	computer and data acquisition system